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Pandemic influenza and health care demand: dynamic modelling

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Abstract. Another influenza pandemic, following those of 1918, 1957, and 1968, is inevitable and could cause substantial social disruption. In order to minimise the effects of a potential pandemic on the population, the Dutch Government has drawn up an influenza pandemic contingency plan. The objective of this study is to simulate the effects of an influenza pandemic in The Netherlands. For simulation, a dynamic model of the spread of pandemic has been developed. As many uncertainties are involved, experts are consulted for their opinions on the underlying model assumptions. The model has been used to simulate the effects of various preventive interventions in terms of avoided hospitalization and mortality. Possible interventions are vaccinations against influenza of certain groups, or the prescription of antiviral medicine (within 48 h after the first symptoms) for each person with an influenza-like illness. The simulation results have been used to support the Dutch Government's decision regarding stockpiling antivirals and securing of pandemic influenza vaccines.

Keywords: Pandemic influenza; Dynamic model; Transmission

1. Introduction

The potential severity of future influenza pandemics and the concomitant demand on the healthcare system, as well as the danger of social disruption, necessitate practical and political preparedness [1,2].

The potential impact of a future influenza pandemic on the Dutch population depends on factors that will not be known before the onset of the pandemic, namely the transmissibility and virulence of the virus and whether or not it will be possible to (quickly) develop a vaccine. Analyses of the impact of different intervention strategies, therefore, take the form of a scenario analysis, in which various alternative sets of assumptions are considered.

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In an RIVM report [2], such an analysis was carried out to estimate the number of hospitalizations and the mortalities under a variety of pandemic scenarios and intervention strategies. In that analysis, the pandemic characteristics were described without explicit consideration of the transmission dynamics, namely by simply assuming attack rates for high- and low-risk groups in the Dutch population. The impact of interventions using vaccination and/or antivirals (neuraminidase inhibitors) was estimated conservatively by considering only their direct effect on the vaccinated or treated individuals. With the latter, individuals will not be able (or less so) to pass the virus on to others, and the interventions also indirectly benefit nonvaccinated and nontreated individuals.

The present analysis extends those in the previous report by including the transmission dynamics of the pandemic virus. This also allows us to compare the effect of differences in timing of vaccination campaigns, and to study the impact of strategies in which antivirals are prescribed to certain groups up until the moment that a newly developed vaccine becomes available.

In the remainder of this brief report, we concentrate on results and conclusions. In Appendix A, we present the details of the mathematical model and motivate the values chosen for those parameters that were not featured in the model of the previous report.

2. Results

We consider the same set of intervention scenarios as in the previous report [2]:

1. Nonintervention
2. Vaccination of high-risk groups (individuals aged >65 years and/or suffering from specific chronic illnesses detailed in Ref. [1]) against pneumococcal infection
3. Therapeutic use of antivirals (i.e., neuraminidase inhibitors) for all patients with influenza-like symptoms, starting within 48 h after the beginning of symptoms
4. Therapeutic use of antivirals for all patients with influenza-like symptoms and prophylactic use of antivirals for nursing home populations
5. Vaccination of high-risk groups (individuals aged >65 years and/or suffering from specific chronic illnesses) before the pandemic reaches The Netherlands
6. Mass vaccination before the pandemic reaches The Netherlands.

In Fig. 1, we compare the impact of interventions (1)–(6) calculated for a representative pandemic scenario with infection attack rates of 50% in all population groups. The impact is measured both in terms of the number of hospitalizations and the number of deaths (Fig. 2). In order to illustrate the effect of the inclusion of the transmission dynamics in these model calculations, we compare the results with those obtained using the model of the earlier report. We observe a substantial 'transmission effect' for all relevant scenarios (3)–(6). For scenario (2), there is no difference, as this intervention strategy does not impact on the transmission of the influenza virus.

The most dramatic correction is observed when an intervention strategy reduces the reproduction number R (defined as the expected total number of secondary cases of infection due to a single primary case) to below one, thus preventing the occurrence of a large outbreak [3]. This situation occurs for scenario (6) for a 50% attack rate. It also

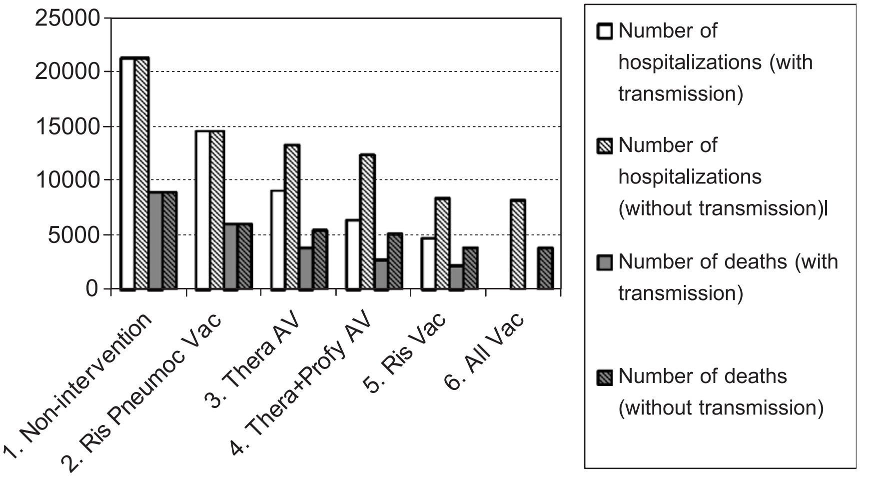

Fig. 1. Total number of hospitalizations and deaths, both with (plain bars) and without (shaded bars) inclusion of the transmission dynamics into the model, for a pandemic with a 50% attack rate in all age/risk groups under the intervention scenarios (1)–(6) described in the main text. The results using the transmission model are based on assumptions and choices of parameter values discussed in Appendix A.

occurs for other scenarios if we assume a somewhat lower attack rate (e.g., for a 25% attack rate, all intervention strategies (3)–(6) reduce R to below one). As our model formulation ignores the possibility of small outbreaks, it predicts zero hospitalizations and zero mortality in these cases.

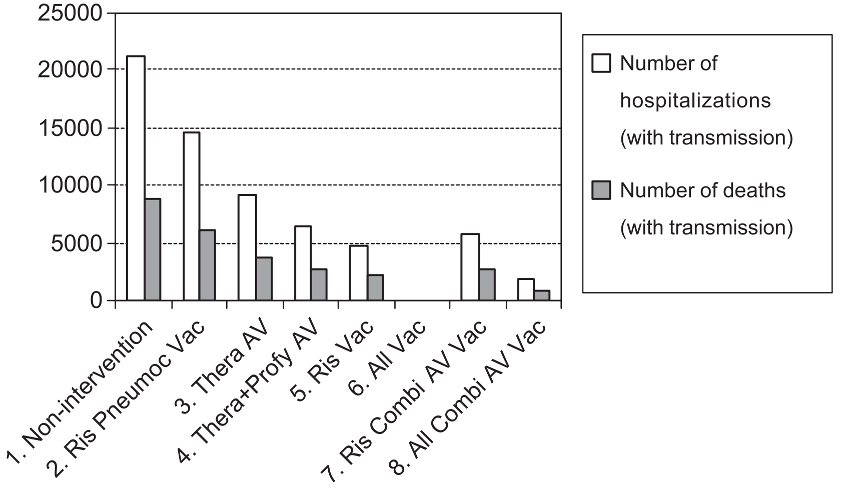

Fig. 2. Total number of hospitalizations and deaths (when including transmission), under intervention scenarios (1)–(6) described in the main text, for a pandemic with a 50% attack rate (in the absence of intervention) in all age/risk groups. These results are based on model assumptions and choices of parameter values discussed in Appendix A.

3. Discussion and conclusion

Our results illustrate that interventions during influenza pandemics can profit greatly from nonlinear effects, and thus provide substantial indirect benefits to nonvaccinated and nontreated individuals. One such effect is the reduction of the transmission intensity that occurs when therapeutic antiviral use leads to a reduced duration of infectiousness. Another such effect is the reduction of the transmission intensity occurring when the number of susceptible individuals is reduced through vaccination or prophylactic antiviral use. This latter effect arises because immune individuals are not only unable to acquire the infection but also unable to pass it on to others.

Beneficial nonlinear effects are always present when an intervention strategy reduces either infectiousness or susceptibility of individuals. The particular strength of such effects in the context of pandemic influenza is directly related to the fairly low value—as compared with for instance measles or pertussis—of the basic reproduction number for influenza assumed here in line with estimates in the literature [4].

For simplicity, we have approximated the mixing between individuals as being homogeneous. Although the inclusion of heterogeneities appropriate for influenza will not affect our main conclusion here, they will make a difference for the detailed impact of different intervention schemes. A particular issue of interest will be the comparative effectiveness of different heterogeneous vaccination schemes [5].

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